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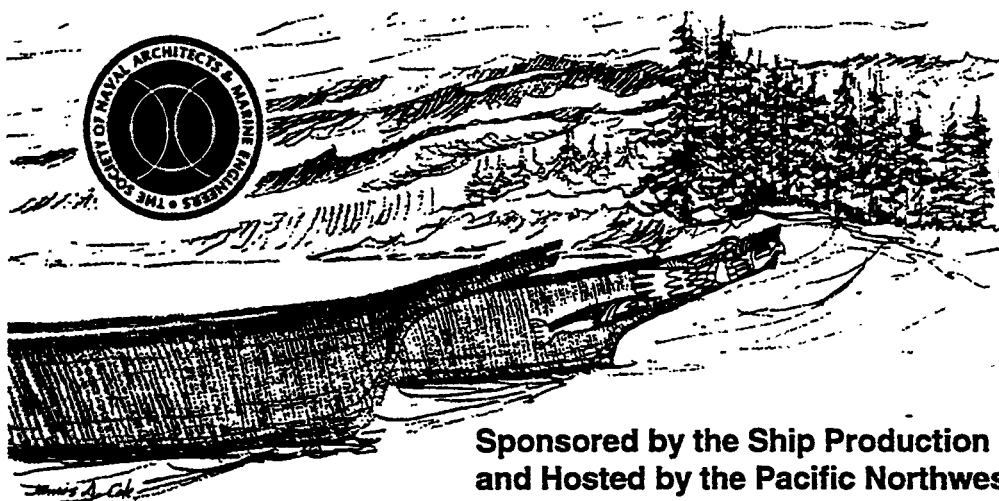
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Past and Present Concepts of Learning: Implications for U.S. Shipbuilders

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ABSTRACT

The experience curve has been used as the model of learning within manufacturing for nearly a century, and has been used as a basis for predicting future performance and for setting performance targets. First, a summary of the experience curve and its underlying premises is given. Then deficiencies in experience-based model of learning are presented. The case is made that an organization that attempts to compete on the basis of incremental improvements on past experience, as represented by past competence and number of units produced, will not be able to compete with the most competent competitors that are using market-driven performance targets and conscious learning and problem solving methods to drive innovation. Two actual examples of learning outside the paradigm of the experience curve are discussed. One method of measuring present learning rates for individual processes is presented. It is concluded that U.S. shipbuilders need to look outside the experience-based model of learning, and the associated idea of series production of standard ships, toward conscious methods of learning and problem solving in order to become competitive in the commercial shipbuilding market.

SUMMARY OF THE EXPERIENCE CURVE LEARNING MODEL

The traditional experience curve model of learning and improvement is founded on the presumption that individuals and organizations learn and performance improves solely as a result of experience gained through repetition of similar work. Along these lines, a recent *Journal of Ship Production* article, entitled "The Effect of Learning When Building Ships," (Erichsen, 1994) defined learning as, "...the ability to do the same task faster and better as *experience is gained...*" (emphasis added). The experience curve function (Thurstone, 1919) can be represented as:

$$y_n = a * n^b \quad (1)$$

where n is the sequential production number of the unit of interest (example: tenth unit produced), Y_n is an objective measure of performance, such as cost or labor hours per ton, for the n th unit produced, a is the value of y for the first unit produced (y_1), and b is an exponent less than one that is usually derived from regression analysis of historical data. Figure 1 shows a typical experience curve with a first unit cost, a , of 100% and $b = -0.074$. This curve gives a second unit cost of 95% of the first unit, a third unit cost of 92.2% of the first unit, down to a cost for the twentieth unit of 80.1% of the first unit.

Some of the reasons why experience can improve performance are as follows.

- Repetition - People and organizations learn to do a task or project better and in less time if the task or project is repeated. This is the basis of the old adage, "Practice makes perfect."
- Specialization - If a job is broken into specific specialized tasks, and then individuals or groups are assigned to each specialized task, (as opposed to the entire job being assigned to a single individual or group) each individual or group can then repeat their specific task continuously, assuming continuous demand, without interruption from other dissimilar types of work and thus learn more effectively and quickly.

While some causal relationship exists between experience, in terms of the number of units produced, and an organization's level of competence and rate of performance improvement, there are problems with associating all learning and related performance improvement only with experience. Before using an experience curve as the basis for predicting future learning and performance improvement these problems must be recognized and addressed.

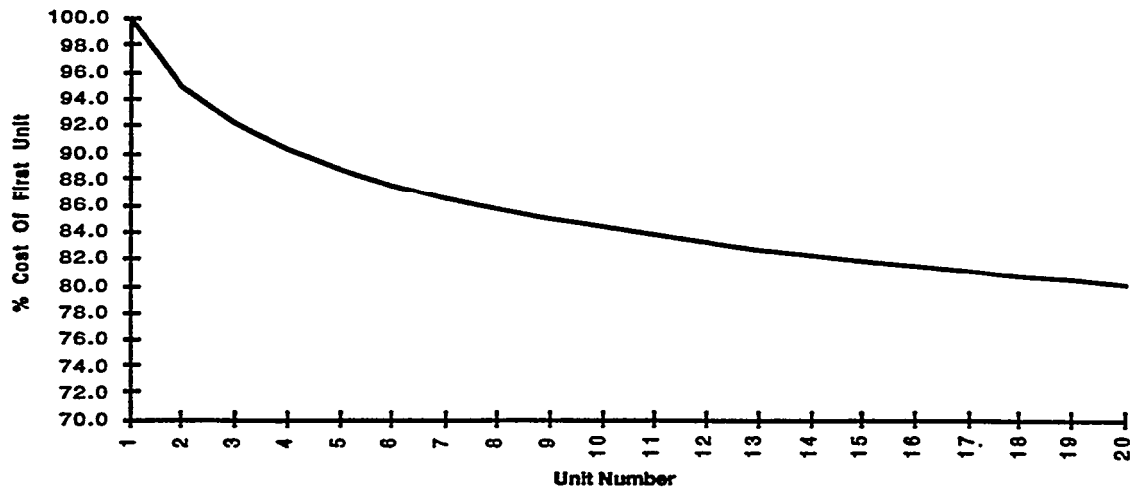


FIGURE 1. TYPICAL EXPERIENCE CURVE, $a = 100$, $b = -0.074$.

DEFICIENCIES IN THE EXPERIENCE-BASED LEARNING MODEL

First, the experience-based model of learning implies that learning can only occur as a result of series production of identical, or at least similar products. According to this model, an organization's capability in producing a product is only a function of its capability when it started to produce the product and the number of products it has produced since it started. Likewise, the organization's rate of learning over time is solely dependent on the rate these products are produced. This would imply that two organizations that started with the same amount and type of experience, and that have produced the same number of a particular product, must now be equally competent at making these products, and must be learning at exactly the same rate per unit. This would also imply that of two organizations that started with the same amount and type of experience, the organization that has built ten units of a product must be more competent than the other organization that has built only two units, and the organization that has built two units must be learning at a faster rate per unit. However, an examination of business performance in many markets shows that these types of relationships do not necessarily hold; that future performance is not necessarily and absolutely dependent upon past production volume and performance. There are other factors that influence competence and learning rate. Some examples of this will be given in a later section of this paper.

Secondly, the experience-based model of learning only looks backward in time, and thus ignores market forces that dictate the future levels of competence and performance improvement rates that will be required to remain competitive. The relevant manage-

ment questions that need to be answered are, "How good are we now?", "How good are the best competitors now?", "How quickly will the best competitors improve over time?", "At what rate must our performance improve overtime in order to become or remain competitive?" The answers to these questions relate to current performance and future market-driven requirements, and have nothing to do with number of units produced in the past or how well the organization performed in producing those units. For example, if a shipbuilder wishes to be competitive building VLCC's in the commercial market two years in the future, that shipbuilder must be capable of at least meeting competitors' anticipated prices, delivery times, and levels of quality at that future time regardless of whether the shipbuilder has built zero or twenty VLCC's in the past. In a competitive shipbuilding market or any type of competitive market past performance is irrelevant, and price, delivery time, and quality performance, as well as rates of improvement required in each of these areas, are established by the most competitive producers in the market. What must be dealt with is current and projected performance of the organization and its most competent competitors. The market-based approach to establishing performance improvement rates and targets is commonly known as target costing, design to cost, or design to price. In the target costing approach,

"Marketing managers first estimate the performance characteristics and market price requirements in order to achieve a desired market share for a proposed product. A standard profit margin is then subtracted from the projected selling price to arrive at the target cost for the product. The product development team must then, through its product and process design decisions, attempt to reach the

product's target cost." [Kaplan & Atkinson, 1989]

Learning and improvement targets are set by the market, and the producers must meet these targets in order to profitably compete. This approach is typical of Japanese manufacturers, and is also being used to some degree by U.S. automobile manufacturers.

A shipyard's rate of learning and improvement is not, and can not be tied only to past experience (as defined by past production volume and performance) if the shipyard wishes to remain or become competitive. To be competitive, a shipbuilder must improve from its present level of performance at a time-based rate dictated by the anticipated market. Requisite present and future levels of competence, and rates of learning and improvement are dictated by the most competent competitors in the market.

Another problem with the experience curve learning model is@ while it accounts for some of the marginal improvement seen in modern competitive commercial organizations, it only recognizes unconscious learning. Unconscious learning is, as implied, learning that is accomplished unconsciously through experience, either through imitation, or more formally through reaction to reward and punishment. What the experience curve learning model ignores is conscious learning which relates to formal education and conscious problem solving. The recognition of the role of conscious learning is important because

"Conscious learning leads to a higher level of competence, in that it is additive and on-going In other words, conscious learning helps to develop learning potential, the potential to control one's own learning. By contrast, unconscious learning is repetitive imitating role models, or repeating behavior which is rewarded and avoiding that which is punished. There is no innovation or change in perspective (with unconscious learning)" [Swieringa & Wierdsma, 1992]

Following are a few key reasons why conscious learning is extremely important to gaining and retaining competence and competitiveness. First, conscious learning begins with learning about the experiences of others so those experiences do not have to be repeated. In this way individuals and organizations can start at a higher level of competence by avoiding having to learn from their own experience what others have already learned and documented, "reinventing the wheel." Second, as implied above, conscious learning results in greater perspective that leads to more open-mindedness toward new ideas. Finally, conscious learning includes the application of

structured problem solving methods, which, when applied by empowered, open-minded personnel facilitates creativity and breakthroughs beyond traditional individual and organizational paradigms, and results in innovation. One common conscious problem solving approach used for process improvement is the classic plan-do-check-act (PDCA) approach, sometimes called the Deming Cycle. In this approach, problem solving teams use brainstorming techniques and one or more of the seven basic quality tools (pareto analysis, process flow charts, check sheets, cause and effect diagrams, histograms, scatter diagrams, and control charts) to develop, implement, review and improve processes. [Chase & Aquilano, 1992]

EXAMPLES OF LEARNING BEYOND THE EXPERIENCE CURVE

Toyota Motor Company [Mishina & Takeda, 1992]
[Chase & Aquilano, 1992]

For several years after the Second World War, very few people in Japan could afford to own a car. Also, immediately following the war Japan's labor productivity was only about one eighth that of the U.S. Toyota was thus challenged with the task of becoming a productive and competitive automobile manufacturer without the benefits of experience, high skill levels, or large production volumes. The company's leaders spent a considerable amount of time studying (conscious learning) successful manufacturing and business methods, and then set about creating the innovative Toyota Reduction System (TPS). The system started with a vision of "better cars for more people." From this vision arose some fundamental principles for the operation of the company, which were

- Ž meet diverse customer preferences,
- Ž do everything with flawless quality,
- eliminate waste,
- deliver the product at a competitive price, and
- deliver the product with perfect timing.

Based on the company's conscious approach to learning and problem solving, and on its vision and principals, Toyota introduced the following innovations into its operations.

- Ž Group Technology - grouping interim products by production requirements, and then organizing production systems to efficiently produce each interim product type.
- Focuses Factory Networks - defining smaller, more specialized factories.
- Just-In-Time production - producing only what is needed when it is needed.
- Kanban - controlling production based on downstream demand or "pull."

- Jidoka - making problems instantly self evident and correcting them immediately.
- Kaizen - proactively and continuously working to replace all product and process standards with better standards.

Had the company relied upon the experience curve model of learning, and had it believed that its future success was entirely dependent upon incrementally improving on its initial low levels of competence and production volume, the company would very probably not have survived. While never having been a volume leader, Toyota became, and still is today, one of the most innovative and competitive automobile companies in the world by utilizing a conscious learning and problem solving approach and using its acquired knowledge to continually push beyond contemporary paradigms.

Avondale Shipyards [Chirillo, 1988]

In the late 1970's Lockheed Shipbuilding had built the lead ship and two follow ships of the LSD-41 Class. When the next flight of ships was bid, Avondale won the contract with a bid of about \$166 million to build LSD-44, as compared to Lockheed's bid of approximately \$225 million. See Figure 2 below.

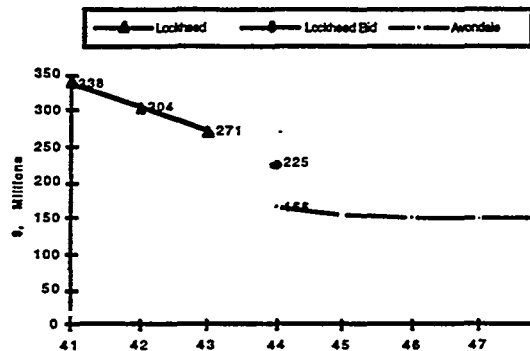


FIGURE 2. LSD-41 CLASS PRICES.

While recognizing that approximately one third of this price difference could be attributed to wage rate differences, Avondale still appeared to be significantly more competent and competitive while not having built even one of these products. How had they gained this level of competence without any experience in the production of the LSD-41 class ship? Their success has largely been attributed to proactive efforts at conscious education, rationalization, and innovation in the late 1970's and early 1980's. As a major part of this effort, they had established a technology transfer agreement with Ishikawajima-Harima Heavy Industries (IHI). With IHI's help, the yard had completely redefined its business and operations practices to support a product-oriented approach to ship production. The principles of

group **technology had** been applied to redefine and group interim products and redefine work processes into process lanes that supported the production of interim product families. This evolution is documented in great detail in the REAPS/NSRP literature. [Avondale Shipyards, Inc., 1982]

Although Lockheed shipbuilding had shown learning and improved performance during the production of the first three ships of the class (from a price of \$338 mil. on the lead ship to \$271 on the third ship), the company had either failed to adequately predict the level of competence that would be required by the market, or failed to successfully take the conscious and proactive actions necessary to remain competitive. Their failure in these areas ultimately resulted in their closure.

A METHOD FOR MEASURING THE RATE OF LEARNING

An organization which has established an environment of continuous improvement has institutionalized processes of conscious learning. In order to be competitive in the commercial market, an organization must not only have established an environment of continuous improvement, but it must also be able to learn as fast as, or faster than, its competitors. Because the ability **to learn** at specific rates is important, it is also important to be able to measure the present rate of learning. Following is a brief discussion of Analog Devices, Inc.'s (ADI) implementation of a methodology for measuring internal rates of learning. [Kaplan, 1990]

Analog Devices produces integrated circuits and electronic devices and systems primarily for converting analog information into digital data. Their products are used in computers, aircraft sensors, scientific and medical instruments, and consumer electronics. In the mid-1980's the company began to see business stagnate in spite of their high quality work force and engineers, continual investment in the latest technology for design and production, and long-term business focus. The company's leaders concluded that they simply were not learning as a company as fast as their competitors. The company's chairman and president went as far as to argue that, "the rate at which individuals and organizations learn may become the only sustainable competitive advantage." [Stata, 1989] This learning should manifest itself in competitive rates of process improvements. The problem then was to determine what rates of process improvement were necessary to remain competitive, and to establish realistic process improvement targets over time based on present performance levels and on projections of the performance of competitors.

The company began to research learning models for manufacturing and business. In this research they identified that in competitive companies

process improvement occurred over *time* (not units produced) such that when some significant measure of process performance requiring improvement such as cost, duration, or defect rate, was plotted on semi-log paper versus time, it would form a decreasing straight line (unless a significant innovation was implemented during the period of measurement). This line would continue downward at a constant rate until some inherent limitations of the process would prevent more improvement, at which time a significant process innovation or breakthrough would be required for performance improvement to continue. See Figure 3.

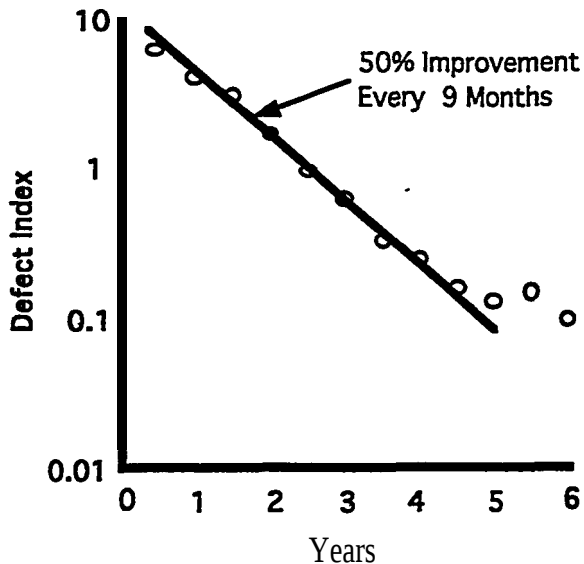


FIGURE 3. EXAMPLE HALF-LIFE GRAPH.

They studied many different types of processes by identifying and measuring a significant defect index for each process, such as error rate, cycle time, inventory level, absenteeism, accident rate, late delivery rate, parts-per-million defective, set-up time, and order lead time. They found that this learning model applied to most types of processes, and that rates of learning in competitive companies were steady over time even as production volume varied. The company then established how much time it would take to achieve a 50% reduction in the defect index of each process, and called this the process half-life measurement. They found that processes with high technical and organizational complexity had process half-lives significantly longer than processes with lower technical and/or organizational complexity, with organizational complexity being the most important factor. The company regularly produced performance reports that showed the half-life graphs and identified the half-life times for each internal process. Table I is a list of some of the company's half-life times for 1989. These numbers represent rates of learning and improvement expressed in half-life months, or the number of months required to reduce the identified process defect indices by half.

Process Defect Index	Half-Life (months)
Errors in purchase orders	2.3
Failure rate, dip soldering process	3.7
Vendor defect level, capacitors	5.7
Accounting miscodes	6.4
Defects per unit, line assembly	7.6
Scrap costs, total manufacturing	13.8
Manufacturing cycle time	16.9
Accident rate	21.5
Late deliveries to customer (+0,-2 weeks)	30.4
Product development cycle time	55.3

TABLE I. SOME 1989 ADI PROCESS HALF-LIVES.

By establishing its present process performance levels and improvement rates, and estimating those of its competitors, a company has some information that it can use to help determine whether it is learning fast enough to compete, and to use as a basis for establishing process performance and improvement targets.

OBSERVATIONS AND CONCLUSIONS

"The rate at which individuals and organizations learn may become the only sustainable competitive advantage." [Stata, 1989] The importance of this statement can not be underestimated in today's intensely competitive environment. However, because the experience curve model of learning has been presented for nearly a century as the only model of learning, as evidenced in this paper's first and second references [Erichsen, 1994] [Thurstone, 1919], many individuals and organizations have fundamental misunderstandings of factors affecting, and approaches to, individual and organizational learning.

It is in these difficult times for the U.S. ship building industry when innovation and breakthroughs are needed most. Unfortunately, during difficult times in U.S. companies in general, one of the first areas where cuts are made is in education and training programs because traditional managers characterize these programs as nonessential overhead rather than investment, and the financial accounting rules reinforce this view by requiring that these costs be expensed as they are incurred. Along these lines, some U.S. shipyards have been downsizing and, in some cases, eliminating their management training, continuing education, and tuition reimbursement programs. Also, many U.S. yards are no longer providing support for their representatives to participate in the NSRP SP-9 Education and Training Panel, and the senior shipyard representatives on the NSRP Executive Control Board have shown a significant lack of support for projects proposed both by SP-9 and SP-5, the Human Resource Innovations Panel, over the last few years. U.S. companies in general, and U.S. shipyards in particular, must begin to recognize that support of education and

training at all levels is an investment in their most important resource and in their future.

There are also political issues related to fundamental misunderstandings of how learning occurs and competence evolves. Many in domestic shipyard leadership and the U.S. government have, at least in the political arena, attributed foreign shipbuilding competitiveness to the experience they have gained supposedly building large numbers of standard commercial ships in series for many years. To quote from the Shipyard Council of America's (SCA) January 6, 1994 *Shipyard Chronicle*,

"For the (U.S.) yards that developed the capabilities to produce complex warships, the transition (to commercial production) will be harder. It is not as some pundits would have you believe simply a matter of making changes in the corporate culture. It is the case that overcoming the advantages of long-term series construction by our competitors makes the task of market entry very difficult."

Because of this belief, or position, some industry leaders and government officials have been lobbying for a federal subsidy for the development and production of standard series commercial ships in US shipyards. Quoting the same issue of *Shipyard Chronicle* referenced above,

"...there should be the development of a Series Transition Payment (STP) program which would help yards make the transition to commercial markets and offset the advantages of series construction that our competitors have enjoyed."

The perspective represented by these statements is fundamentally flawed in several ways. First,

only a very small portion of ocean-going ships that have been built in the past several years have been part of standard series production runs. Figure 4 below is a graph of some of the data presented by a representative of the Association of Western European Shipbuilders (AWES) at the Shipyard Industrial Game put on by the Center for Naval Analysis in December 1993. This data shows that 85% of the inquiries received by AWES shipyards in 1993 were for order quantities of three vessels or fewer, with over 70% of inquiries for ships in quantities of one or two. The AWES representative presented this data specifically to point out to U.S. shipbuilders who were present at the Shipyard Industrial Game that the "long-term series construction" market is extremely small, and it has been very small for many years. In fact, on average ship owners are looking for ships with many custom features, generally in quantities of one or two. Foreign shipbuilders who recognize this market truth have been, and are now, targeting these customers and meeting their demands.

Second, when these industry representatives attempt to apply the experience-based learning model to ships as the units of production, the implication is that the production of a ship is a traditional one-off construction project. This perspective fails to recognize that modern shipbuilding is a manufacturing process that is subdivided into the fabrication and assembly of many families of similar interim products using a group technology-based product work breakdown structure. Whatever experience-based learning and improvement that is being gained by competitive shipbuilders is being gained at the interim product level, not at the level of the final product. When viewed from a manufacturing perspective, what becomes important from the standpoint of gaining experience is repeating the manufacture and assembly of similar interim products, regardless of the type of ship to which any one particular interim product might happen to belong.

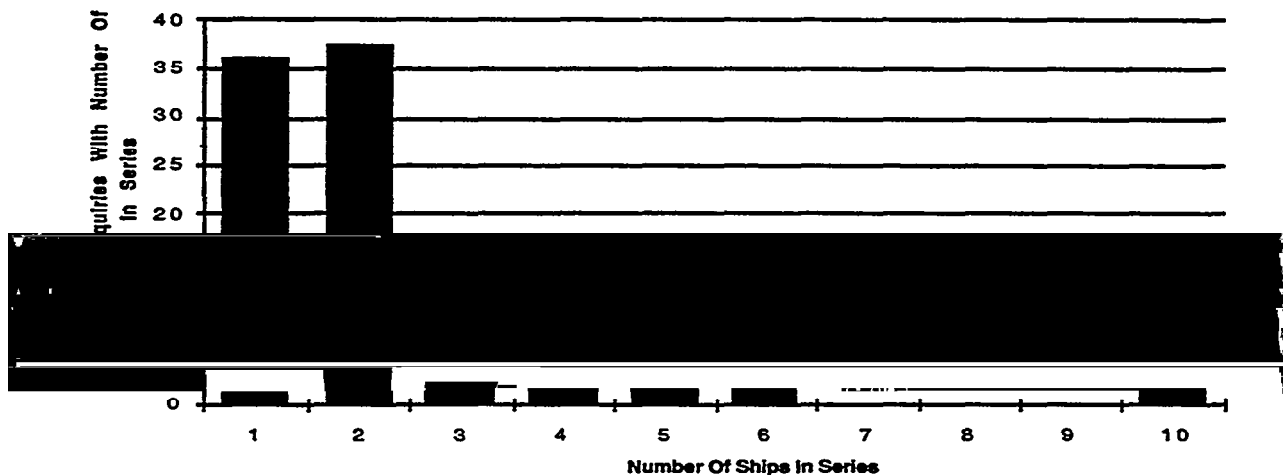


FIGURE 4. 1993 AWES % INQUIRIES BY PROPOSED NUMBER OF SHIPS IN SERIES.

The process of assembling a "flat block" is essentially the same whether that particular "flat block" is part of a container ship or part of a product carrier. If a shipyard has done an adequate job of defining and using a product-oriented design and production approach, standardizing its interim product type-s and production processes, significant commercial shipbuilding experience can be gained without the need for standard series ships.

Finally, as discussed throughout this paper, the views expressed by some shipyard representatives and the SCA relative to series production demonstrate the typical misunderstanding of the learning process: that leaning is based only on experience. This perspective ignores the more significant potential of conscious learning and problem solving. Only through conscious approaches to learning can organizations hope to break free of ongoing repetition and incremental improvement of past noncompetitive practices, and begin to learn and improve at competitive rates.

Competitive companies do not allow themselves to be limited by their past experiences. Ultimately, the shipyards that compete successfully in the commercial market will be those that have made, and continue to make, considerable conscious effort to learn the market, learn their competitors' and their own capabilities, and learn what the best competitors in other industries are doing to be successful. These yards will be consciously apply problem solving methods and their growing knowledge to create innovative solutions to their problems and improved ways of doing business. Those yards that fail in their attempt to enter the commercial market may be trying to ride the experience curve to competitiveness as their competitors pass them by.

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